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Washington,
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An Analysis Using the Combined Stand Prognosis/Douglas-fir Tussock Moth Outbreak Model and the FORPLAN Linear Programing Model on the Clearwater and Malheur National Forests

Wayne E. Bousfield

James E. Brickell

John C. Cleeves

Richard L. Dezellem

Tommy F. Gregg

Thomas H. Hofacker

Ralph R. Johnson

Joseph W. Lewis

George M. Lightner

Thomas P. Quinn

Marc R. Wiitala

Preface

This report presents a methodology for evaluating the economic impact of the Douglas-fir tussock moth on forest management objectives and for assessing the economic efficiency of alternative pest management strategies.

The methodology was applied to two National Forests: the Clearwater in Idaho and the Malheur in Oregon. Forest Service staff of the Clearwater and Malheur National Forests, the Northern and Pacific Northwest Regions, and the Washington Office conducted the analysis.

This report was prepared by Forest Pest Management, State and Private Forestry, Forest Service, U.S. Department of Agriculture, P.O. Box 2417, Washington, D.C. 20013.

For information contact:

Joseph W. Lewis (703) 235-1554
Thomas H. Hofacker (703) 235-1554

Summary

This analysis provides the land manager with information about the likely economic impact of the Douglas-fir tussock moth on forest management objectives and the most efficient actions to deal with this pest on a long-term basis.

Our objectives were to evaluate the potential effects of Douglas-fir tussock moth outbreaks on the Clearwater and Malheur National Forests over a 150-year period, and to determine the economic efficiency of several strategies for dealing with these outbreaks. The basis of the analysis was the land and resource management planning process used by both Forests.

The methodology involved three computerized models:

1. The Douglas-fir Tussock Moth Model to simulate the effects of tussock moth outbreaks;

2. The Stand Prognosis Model to project forest growth and yield; and

3. The FORPLAN Linear Programing Model to determine the relative economic efficiency of four land management scenarios.

Four scenarios were analyzed on each Forest:

1. No outbreaks over 150 years;

2. No control of simulated outbreaks;

3. Peak phase control, or control in the second year of an outbreak; and

4. Decline phase control, or control in the third year of an outbreak.

The most recent land management planning solution for each Forest served as the no-outbreaks scenario. This scenario does not account for tussock moth infestations.

The same process used to develop the no-outbreaks scenario was also used in the three outbreaks scenarios, except that the outbreak scenarios simulated tussock moth infestations to produce new yield tables. These new tables were then entered into the FORPLAN Linear Programing Model.

Management objectives, which might constrain how the forest resource is managed, were entered into FORPLAN. All management constraints applicable to the no-outbreaks scenario were also applied to the outbreak scenarios.

For each scenario, FORPLAN tested many combinations of silvicultural treatments, harvest schedules, and tussock moth control (where applicable) to arrive at the combination of activities that was most efficient, that is, had the highest present net value.

Although the no-outbreaks scenario resulted in the greatest present net value on both Forests, it is unlikely that these Forests will be free from tussock moth outbreaks for 150 years. When outbreaks were simulated, the peak phase control scenario produced the highest present net value, followed by decline phase control. The no-control scenario had the lowest present net value. The results of the analysis suggest that over a 150-year period the tussock moth threatens forest productivity under a variety of circumstances and that control is an economically efficient forest management practice.

The results also suggest that tussock moth damage can be reduced more efficiently with a combination of control and intensive silvicultural treatments than with either tactic alone. Under the no-outbreaks scenario, maximum present net value was achieved with relatively nonintensive silvicultural management. Under the outbreak scenarios, however, the most economically efficient resource allocation involved tussock moth control and more intensive management, such as multiple thinnings in both existing and regenerated stands.

Contents

Illustrations

Tables

Introduction

Managing forest insect pests goes hand-in-hand with managing forest resources. Forest land managers often face the question of whether to allow an insect infestation to run its course and accept the consequences or to attempt to control the infestation and reduce damages.

Many factors should be considered when deciding if insect infestations need to be controlled. The economic consequences of each option should always be included in the decisionmaking process.

Since the passage of the National Environmental Policy Act of 1969 (Public Law 91-190), Forest Service and State personnel have conducted economic evaluations of individual forest pest outbreaks on an outbreak-by-outbreak basis on both public and private lands. In contrast to these individual evaluations, this study presents a methodology for assessing the economics of pest impacts in a broader context of long-term planning.

This approach evaluates the probable economic effects of simulated Douglas-fir tussock moth (*Orgyia pseudotsugata* McD.) outbreaks on the Clearwater National Forest in Idaho and the Malheur National Forest in Oregon over a 150-year period. These Forests were selected because they have a history of Douglas-fir tussock moth outbreaks, and another outbreak is expected in the general area within the next few years.

Economic impacts of the tussock moth were examined by linking together three computer models: a pest outbreak model, a stand growth model, and an economic optimization model. Several strategies for dealing with the outbreaks were evaluated to determine which course of action was most efficent.

The objectives of this analysis were to determine

- The effects of a sequence of Douglas-fir tussock moth outbreaks on two National Forests; and

- The economic efficiency of several alternative pest management strategies for dealing with these outbreaks.

Because this technique evaluates probable pest impacts before outbreaks actually occur, it can help land managers select the most economically efficient forest management practices over the long run.

The Insect

The Douglas-fir tussock moth is an insect that feeds on the foliage of Douglas-fir and true firs in Western North America. Severe outbreaks of tussock moth have been recorded in Arizona, British Columbia, California, Idaho, Nevada, New Mexico, Oregon, and Washington (Wickman and others 1981).

In most years, the insect is difficult to find. But periodically, tussock moth populations explode. Their feeding results in extensive tree mortality, top-kill, growth retardation, and weakening of trees. Many weakened trees are eventually killed by bark beetles (Wickman and others 1981). Outbreaks are usually short lived: High population levels last only 1 or 2 years.

Outbreak areas characteristically exhibit four phases (Wickman and others 1973):

1. A release phase in which populations grow rapidly to outbreak levels (first year);

2. A peak phase in which populations reach maximum density (second year);

3. A decline phase in which insect numbers begin a rapid decline (third year); and

4. A postdecline phase in which populations return to endemic levels (fourth year).

The Hosts

The major tree species affected by the Douglas-fir tussock moth are Douglas-fir, grand fir, and white fir (Brooks and others 1978). After the insects have eaten the foliage from the preferred hosts, they may feed on subalpine fir, lodgepole pine, ponderosa pine, western hemlock, Engelmann spruce, and western larch.

Outbreak Suppression

Douglas-fir tussock moth suppression programs first began in 1947, when 413,500 acres in portions of Idaho, Oregon, and Washington were treated with DDT (Evenden and Jost 1947).

Currently, both biological and chemical insecticides are registered by the U.S. Environmental Protection Agency for aerial application to control Douglas-fir tussock moth. With an effective early detection program, outbreaks can be treated in their peak phase, the second year, before much defoliation or damage occurs. Large portions of past outbreaks have often been treated in their decline phase, after some damage has occurred.

Many forest and pest management specialists believe Douglas-fir tussock moth losses can be reduced over the long run by establishing thrifty stands on proper sites. However, the creation of these forest conditions will take a great deal of time and will not completely eliminate tussock moth outbreaks. Silvicultural management and suppression of outbreaks as they occur should be considered.

Clearwater National Forest

The Clearwater National Forest is located in the Bitterroot Mountains of north-central Idaho near the town of Orofino (fig. 1). The Forest is bounded on three sides by four other National Forests: the Lolo and Bitterroot in Montana and the Nezperce and St. Joe in Idaho. On the west, the Clearwater is bounded by a mixture of private and other public lands.

The Forest covers 1,838,730 acres, of which about 1,200,000 acres are classified as commercial forest land. There are 146,083 acres of private and other public lands intermingled within the Forest boundaries.

Ninety percent of the commercial forest land is mixed conifer, and the remaining ten percent is predominantly lodgepole pine.

Although 90 percent of the commercial forest land on the Clearwater contains tussock moth host trees, past tussock moth infestations have been confined to the Palouse Ranger District, a 150,000-acre area that comprises about 12.5 percent of the Clearwater's commercial forest land.

Malheur National Forest

The Malheur National Forest is located in the Blue Mountains of eastern Oregon near the town of John Day (fig. 1). The Malheur is bordered on the north by the Umatilla National Forest, on the west by the Ochoco National Forest, on the east by the Wallowa-Whitman National Forest, and on the south by a mixture of private and other public lands. A total of 1,459,422 acres is administered by the Malheur. About 1 million acres are classified as commercial forest land.

The Malheur is principally in the ponderosa pine forest cover type. The Forest is classified as 40 percent ponderosa pine, 10 percent lodgepole pine, and 50 percent mixed conifer (Douglas-fir and white fir/grand fir). Stand composition varies from 25 percent tussock moth host trees in the ponderosa pine stands to 75 percent tussock moth host trees in the mixed conifer stands.

Past tussock moth infestations on the Malheur have occurred throughout the Forest.

Figure 1

Location of Clearwater and Malheur National Forests

A historical review of the tussock moth in the Pacific Northwest suggests that regional outbreaks tend to be cyclic, with about 9 to 12 years between outbreaks.

Clearwater National Forest

The first recorded outbreak on the Clearwater National Forest occurred on the Palouse Ranger District and surrounding private lands in 1944 (Evenden and Jost 1947). By 1945, additional, small infestations were found in Genesee and Viola, Idaho. In 1946, 350,000 acres were defoliated on all ownerships in and around the Palouse Ranger District. In 1947, 400,000 acres of mixed ownerships were treated with DDT (Evenden and Jost 1947).

In 1955, a tussock moth infestation was observed near the Clearwater National Forest on 30,600 acres of private land east of Orofino. This outbreak subsided naturally.

During 1961-65, tussock moth outbreaks occurred on the Palouse Ranger District and surrounding private lands (Tunnock 1965). In 1965, 120,000 acres of Federal and private lands were treated with DDT (Scribner 1965).

The last outbreak on the Clearwater National Forest began in 1971 and ended in 1974. In 1971, ornamental trees were defoliated in Troy and other places in northern Idaho (Tunnock and Honing 1971). By 1973, defoliation was visible on about 70,000 acres of mixed ownership on the Palouse Ranger District and on 120 acres of private land east of Orofino. In 1974, 74,000 acres were treated with DDT; 17,000 of these acres were on the Palouse Ranger District (Almas and others 1975).

Malheur National Forest

The first recorded outbreak of the Douglas-fir tussock moth on the Malheur National Forest was detected in 1928 near Seneca, Oreg. The outbreak subsided in 1929 (Buckhorn 1947).

In 1937, an outbreak of about 80,000 acres occurred on Rudio Mountain. Considerable tree mortality and top-kill were reported before the outbreak subsided in 1939.

In 1947, two small outbreaks--about 320 acres near Snow Mountain and 640 acres at Gold Hill--were discovered. The Snow Mountain outbreak collapsed in 1947, but the outbreak at Gold Hill expanded to about 1,500 acres before collapsing in 1948.

In 1963, a 15-acre defoliated area was discovered on Antelope Mountain on the Malheur National Forest. In 1964, additional outbreaks occurred on King Mountain and Gold Hill. In 1965, 62,650 acres were treated with DDT (Perkins and Dolph 1967).

In 1973, the tussock moth defoliated 1,230 acres on Bureau of Land Management, State, and private lands near Ironside Mountain on the east side of the Malheur National Forest. The extent of damage is unknown. The outbreak subsided in 1973 (Graham and others 1975).

Study Design

Model Linkage

The methodology used in this study linked three computerized models to (1) simulate the effects of tussock moth outbreaks; (2) project forest growth, yields, and volumes; and (3) determine the relative economic efficiencies of four land management scenarios (fig. 2). The following models were used:

- An insect outbreak model.--The Douglas-fir Tussock Moth Outbreak Model (DFTM Model) (Colbert and others 1979) simulated tussock moth outbreaks and their effects on forest stands.

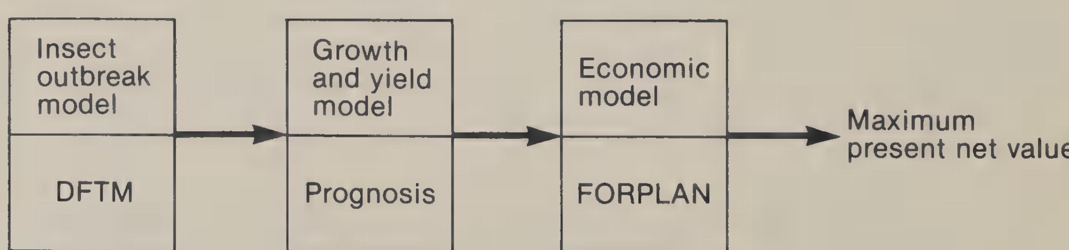
- A growth and yield model.--The Stand Prognosis Model (Prognosis) (Wykoff and others 1982) projected growth and yield of mixed species conifer stands.

- An economic optimization model.--The FORPLAN Linear Programing Model (FORPLAN) served as the economic component and determined maximum present net values for each scenario.

NOTE: Prognosis and the DFTM Model were recently combined into one model (Monserud and Crookston 1982) that accounts for tussock moth outbreaks. Appendix A describes the models.

Figure 2

Model Linkage



Scenarios

Four land management scenarios were processed through the models. The scenarios were as follows:

- No outbreaks.--No outbreaks occur over the 150-year period.

- No control.--Periodic Douglas-fir tussock moth outbreaks are simulated over the 150 years but are not controlled.

- Peak phase control.--All outbreaks over the 150 years are controlled in the second year of the outbreak.

- Decline phase control.--All outbreaks over the 150 years are controlled in the third year of the outbreak.

All four scenarios were evaluated on both the Clearwater and Malheur National Forests. Of the four scenarios, the one with the highest present net value was the most economically efficient for that Forest.

Before this study, both Forests developed a long-range planning process. The Forests entered inventory data and silvicultural treatment options into Prognosis to produce various yield tables representing each forest stand. Some yield tables reflected no silvicultural treatment; some reflected only precommercial thinning; some reflected commercial thinnings; and so forth. All yield tables were then processed through FORPLAN, which

1. Discounted all costs and revenues associated with each yield table and calculated present net values;

2. Compared many possible harvest schedules among all stands;

3. Applied all appropriate constraints; and

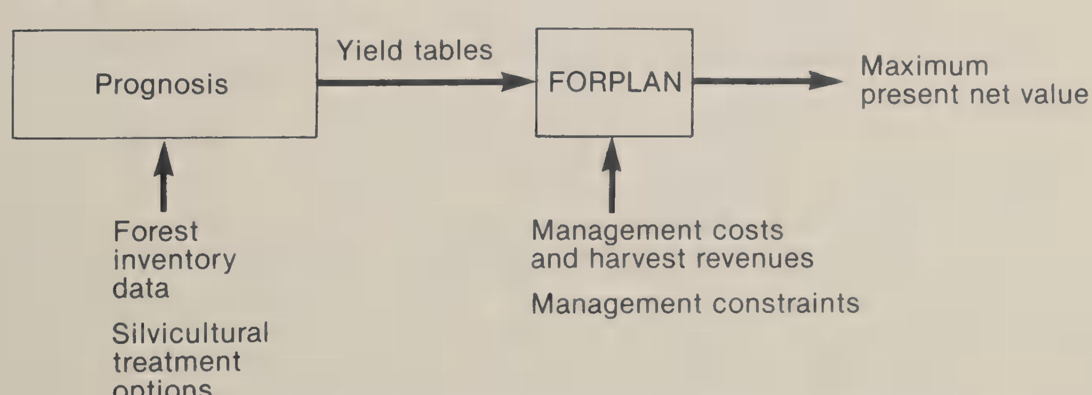
4. Determined which combination of silvicultural treatments and harvest schedules resulted in the highest present net value for the entire Forest.

On the Clearwater, the FORPLAN solution is based on the "proposed land allocations." On the Malheur, the solution is based on the "current land allocations."

In this study, the proposed land allocations were used as the no-outbreaks scenario for the Clearwater; the current land allocations were used as the no-outbreaks scenario for the Malheur (fig. 3).

Figure 3

No-Outbreaks Scenario



The no-outbreaks scenario does not account for tussock moth infestations over the 150-year planning period. Yet when infestations occur, they will alter the expected yields, thus potentially affecting the FORPLAN solution.

To determine how tussock moth infestations affect management efficiency, the study analyzed the three outbreak scenarios.

The process normally used by the Forests to develop inventory data and yield tables was used in the three outbreak scenarios. The only difference was that--for the outbreak scenarios--tussock moth infestations were simulated by the Combined Prognosis/DFTM Model to produce new growth and yield tables. These tables were then entered into FORPLAN. Figures 4 and 5 depict the outbreak scenarios.

Figure 4

No-Control Scenario

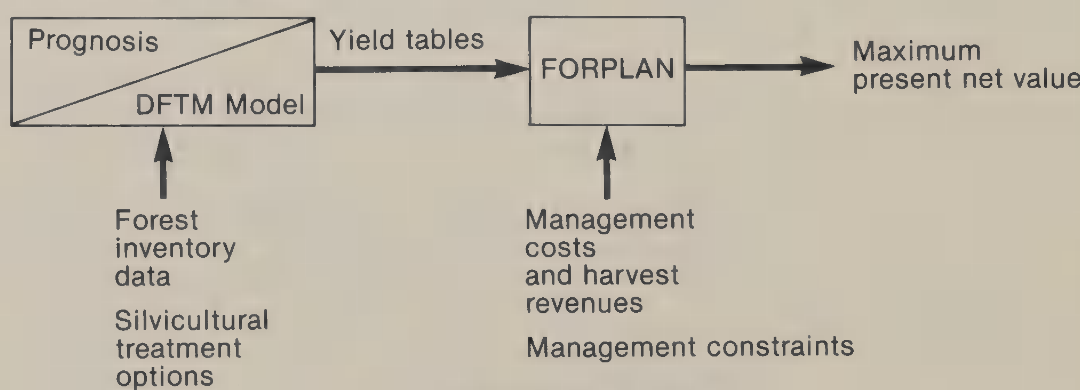
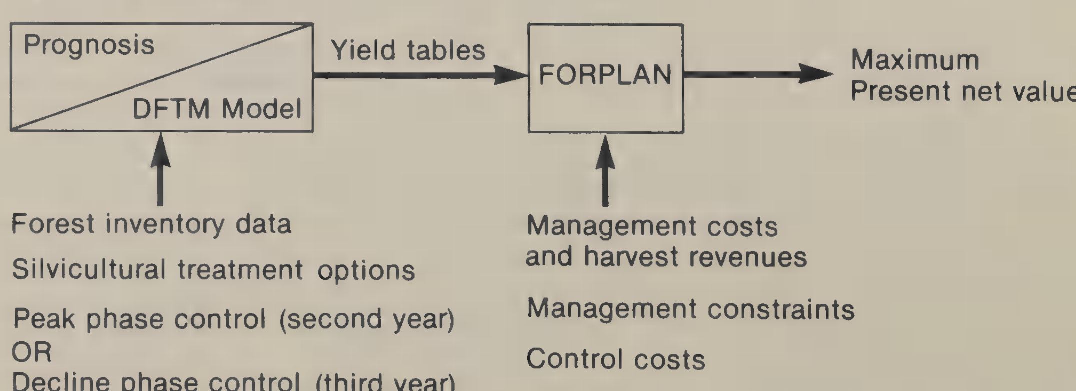


Figure 5

Control Scenarios



Assumptions and Background Data

Assumptions and background data used in the analysis of the scenarios follow:

- Forest inventory information for the Clearwater and Malheur National Forests was obtained from existing data bases. Appendix B describes the inventory designs for the Forests.

- Since only the Palouse Ranger District of the Clearwater has historically been subject to tussock moth infestations, outbreaks were simulated for this portion of the Forest only. On the Malheur, outbreaks were simulated for the entire Forest.

- Two real discount rates were used in the analysis: 4 percent and 7.125 percent. These are the rates specified for use in forest planning. All costs and revenues used to determine the allocations and harvest schedules that maximize present net values for each scenario were discounted at 4 percent. Using the optimal solution selected at the 4 percent rate, present net values were recalculated at 7.125 percent. This procedure is used in the forest planning process.

- All costs and revenues were adjusted to first quarter 1978 dollars using the implicit price deflators for gross national product index.

- All timber values were based on stumpage prices derived from historical sale data. Values varied by species, diameter class, and slope. Appendix C displays stumpage prices for both Forests.

- Real increases in timber prices (increases above inflation) were derived from those projected to the year 2030 in "A Recommended Renewable Resources Program, 1980 Update," FS-346; U.S. Department of Agriculture, Forest Service; September 1980; and in "Stumpage Price Projections for Selected Western Species," Research Notes PNW-367, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; Richard Haynes, Kent Connaughton, and Darius Adams; 1980.

- All timber management costs were based on recent cost data. Tussock moth control costs were estimated at $10 per acre per outbreak (first quarter 1978 dollars) for both Forests.

° The demand curve for timber was assumed to be horizontal, meaning that fluctuations in the amount of timber sold by the Forests would not affect the unit price. It would have been more realistic to allow timber prices to fluctuate as the amount of timber brought to market fluctuates. However, to do so would have involved a large data collection effort and would probably have had very little, if any, effect on the outcome of the study. The horizontal demand curve assumption is consistent with regional and national forest planning direction.

° Tussock moth control was assumed to be about 90 percent effective on all infested acres where control took place. This assumption was based on experience and results of field experiments. Actual control effectiveness on individual stands may be more or less than 90 percent.

Evaluation Process

This section describes how the three models (DFTM Model, Prognosis, and FORPLAN) were used to determine the most economically efficient scenario for each Forest.

DFTM Model

First, historical outbreak data were used to calibrate the DFTM Model. Based on these data, the minimum time between regional outbreaks was specified as 9 years for the Clearwater and 10 years for the Malheur. A regional outbreak is a group of infestations that are synchronized over a large geographic area, such as northern Idaho or eastern Oregon (Brooks and other 1978). The probability of a regional outbreak occurring in any year after the minimum period between outbreaks had expired was specified as 0.4 for the Clearwater and 0.1 for the Malheur.

Once the model was calibrated, the year of the last major regional outbreak--1973 for the Clearwater and 1965 for the Malheur--was used as the starting point for simulating tussock moth outbreaks over 150 years.

The model then simulated 12 outbreaks for the Clearwater and 10 outbreaks for the Malheur. The years of the simulated regional outbreaks are shown below:

Clearwater National Forest	Malheur National Forest
1986	1985
1995	2003
2008	2019
2020	2040
2029	2053
2039	2072
2049	2085
2059	2095
2072	2108
2083	2119
2097	
2108	

Not all forest stands in any given area were included in any given regional outbreak. Therefore, once a regional outbreak was generated, the model determined the likelihood of a particular forest stand being infested by calculating a conditional probability based on site and stand characteristics. If this conditional probability was greater than a randomly generated number (between 0 and 1), then the stand was included as part of the regional outbreak.

If a stand was included in a regional outbreak, the model determined the extent of damage--if any--based on tussock moth population levels and amount of foliage. (These factors are based on stand and historical infestation data.)

For the peak and decline phase control scenarios, the model simulated insecticide treatments by altering insect mortality or population growth rates.

Appendix D describes the DFTM Model inputs.

Prognosis

Outputs from the DFTM Model were interfaced with Prognosis to project volumes.

As mentioned earlier, Prognosis was recently combined with the DFTM Model. The insect impact simulations from the DFTM Model were integrated into the growth and yield equations of Prognosis to produce volume projections (yield tables) that took into account stand characteristics, insect population data, and control treatment effectiveness.

For each outbreak scenario, the Combined Prognosis/DFTM Model generated several yield tables representing the entire Forest. These tables reflected various silvicultural treatment options. The no-control scenario, for example, had a set of yield tables reflecting nonintensive management with no control; a second set of tables reflecting low-intensity management with no control; another set reflecting intensive management with no control; and so forth. The other scenarios were treated similarly.

In the simulation process, many stands were not included in the regional outbreaks but were nevertheless part of the outbreak scenarios. The yield tables for these stands reflected no tussock moth impact, but still varied by level of management intensity and, along with the impacted yield tables, were available to FORPLAN.

FORPLAN

Once the yield tables were developed for all scenarios, they were entered into FORPLAN.

Every yield table had associated silvicultural treatment costs, tussock moth control costs (where applicable), and harvest revenues. This economic information was entered into FORPLAN. All silvicultural options available in the no-outbreaks scenario were also available for the other scenarios.

Management objectives, which might constrain how the forest resource is managed, were also entered into FORPLAN. Examples of such constraints include nondeclining, even-flow objectives, which limit harvest volumes; avoidance of sediment production; management for recreation or wildlife habitat, which might preclude harvesting some stands; and so forth. All management constraints applicable to the no-outbreaks scenario were also applied to the outbreak scenarios.

Relatively stringent constraints on maximum harvest volumes were applied on the Clearwater. On the Malheur, no such constraints were imposed; however, maximum harvest volumes were subject to biological limitations as well as long-term sustained-yield capacities.

For each scenario, FORPLAN tested many combinations of silvicultural treatments, harvest schedules, and control (where applicable) to arrive at the combination of activities that was most efficient, that is, had the highest present net value.

Remarks

The strength of using FORPLAN as the economic component in this analysis is that many possible combinations of tussock moth control and silvicultural treatments can be tested for each scenario to identify the combination that is most economically efficient. For example, the present net value reported for the peak phase control scenario is the largest of many that were tested for that scenario. FORPLAN went through the same procedure for each of the other scenarios. Thus, when we compare the present net values for the four scenarios, we know that we are comparing the most efficient combination of activities for one scenario against the most efficient combination for each other scenario.

Under the no-control scenario, FORPLAN was allowed to reschedule harvests and change silvicultural treatment options in an effort to offset damages in infested stands without incurring tussock moth control costs. Hence, the no-control scenario could conceivably reflect a situation in which infestations subside naturally and damage is mitigated by rescheduling harvests.

Present net values for the scenarios on each Forest were developed under the same constraints, objectives, inventories, and so forth. The scenarios on each Forest, therefore, are directly comparable in all respects. However, because constraints and objectives were different on the two Forests, one Forest cannot be compared to the other.

Results

Present Net Values

As expected, the no-outbreaks scenario resulted in the greatest present net value on both Forests. Without tussock moth outbreaks, the most economically efficient combination of silvicultural treatments and harvest allocations will result in a present net value discounted at 4 percent of $1.349 billion on the Clearwater and $1.434 billion on the Malheur (tables 1 and 2).

NOTE: Appendix E shows the economic values discounted at 7.125 percent. The higher discount rate caused all values to be lower but did not affect the ranking of the scenarios.

Table 1--Economic values (discounted at 4 percent) for the Clearwater National Forest

Scenario	Present value of benefits	Present value of costs	Present net value
		Millions of dollars	
No outbreaks	1,655	306	1,349
No control	1,642	313	1,329
Peak phase control	1,655	310	1,345
Decline phase control	1,650	313	1,337

Table 2--Economic values (discounted at 4 percent) for the Malheur National Forest

Scenario	Present value of benefits	Present value of costs	Present net value
		Millions of dollars	
No outbreaks	1,520	86	1,434
No control	1,248	79	1,169
Peak phase control	1,511	93	1,418
Decline phase control	1,336	85	1,251

Of course, it is unlikely that these Forests will be free from tussock moth outbreaks for 150 years. It is more relevant, therefore, to examine the three outbreak scenarios. The ranking of these scenarios by present net value was the same for both Forests. Peak phase control produced the highest present net value, followed by decline phase control. The no-control scenario had the lowest present net value.

Yields

The harvest volumes for the first five decades of each Forest's planning period are shown in table 3. The planning period began in 1980 and ended in 2130.

Table 3--Harvest volumes for scenarios

Scenario	Clearwater National Forest	Malheur National Forest
	Million cubic feet	
No outbreaks		
First decade	425	493
Second decade	552	493
Third decade	718	493
Fourth decade	915	493
Fifth decade	915	493
No control		
First decade	425	399
Second decade	552	399
Third decade	718	399
Fourth decade	909	399
Fifth decade	909	399
Peak phase control		
First decade	425	507
Second decade	552	507
Third decade	718	507
Fourth decade	915	507
Fifth decade	915	507
Decline phase control		
First decade	425	423
Second decade	552	423
Third decade	718	423
Fourth decade	916	423
Fifth decade	916	423

Two differences in the harvest levels for the first five decades are readily apparent. First, for any given scenario, harvest volumes remained constant for the first five decades on the Malheur, yet they changed substantially on the Clearwater. Second, harvest volumes differed among scenarios on the Malheur, yet were virtually the same for any decade for all the scenarios on the Clearwater. These differences resulted from the different constraints applied to meet management objectives on each Forest. Harvest volume constraints were more restrictive on the Clearwater; thus, volume levels for the first five decades remained almost the same for each scenario.

A somewhat surprising result of the analysis on the Malheur was that harvest volumes were higher in the peak phase control scenario than in the no-outbreaks scenario. This result raises an obvious question: How can timber volumes be higher with tussock moth outbreaks than with no outbreaks?

The explanation lies in the process used to evaluate the many possible combinations of silvicultural treatments and tussock moth control options.

All scenarios were processed through FORPLAN with the objective of maximizing present net values. Under the no-outbreaks scenario, maximum present net value was achieved with relatively nonintensive silvicultural management. Under the outbreak scenarios, however, the most economically efficient resource allocation involved more intensive management, such as multiple thinnings in both existing and regenerated stands. Appendix F shows the volumes and acres of precommercial and commercial thinnings for each scenario. Generally speaking, the higher the level of management intensity, the lower the impact of the tussock moth. Thus, the tussock moth induces more intensive silvicultural management, which is reflected in the optimal FORPLAN solution.

Because the most economically efficient treatments and schedules are those that offset volume loss, a higher harvest volume is produced when outbreaks are projected. In a sense, as the model attempts to reduce monetary losses due to tussock moth, it increases volume production through intensive management. Volumes would be substantially lower in the outbreak scenarios if the relatively nonintensive prescriptions of the no-outbreaks scenario were applied--even if the outbreaks are controlled.

On both Forests, the "objective function" of FORPLAN is to maximize present net value, not timber volumes. If the objective had been to maximize timber volumes, a different solution would have been obtained. In fact, it can be shown that attempts to maximize volume yields over time would result in lower present net values. The present net values would be lower because the additional time and expense necessary to achieve increments of volume above a certain level would not be offset by the value of the volume increments.

Long-term sustained-yield capacities for all scenarios on the two Forests are shown in table 4. These capacities vary slightly under the different scenarios.

Table 4--Long-term sustained-yield capacities for scenarios

Scenario	Clearwater National Forest	Malheur National Forest
	Million cubic feet per decade	
No outbreaks	915	504
No control	909	480
Peak phase control	915	528
Decline phase control	916	480

Losses

Discounted values of the losses caused by the tussock moth under each of the outbreak scenarios on the two Forests are shown in tables 5 and 6 (column 2). Losses are defined as the difference in present net value between an outbreak scenario and the no-outbreaks scenario. For example, on the Malheur National Forest, present net value is $265 million less under the no-control scenario than under the no-outbreaks scenario. This difference represents a loss of $265 million if tussock moth outbreaks occur but are not controlled. The difference between the peak phase control scenario and the no-outbreaks scenario is $16 million, indicating that losses can be held to $16 million if outbreaks are treated during the peak phase.

Benefits

The net benefit of controlling tussock moth outbreaks is the value of losses averted under each control scenario. The present values of losses averted are shown in tables 5 and 6 (column 3).

Loss averted is defined as the difference in losses with and without tussock moth control. On the Malheur, for example, treating outbreaks during the peak phase reduces losses from $265 million under the no-control scenario to $16 million. This difference amounts to net benefits of $249 million attributable to peak phase control. The $249 million can be calculated more directly by subtracting the present net value (tables 5 and 6, column 1) of the no-control scenario from the present net value of the peak phase scenario ($1,418 million - $1,169 million = $249 million).

Control Costs

Tussock moth direct control costs were specified as $10 per acre (first quarter 1978 dollars) for both peak and decline phase control scenarios. The total discounted, direct control costs over 150 years were $1.6 million for the Clearwater and $4.9 million for the Malheur. Administrative delay was assumed to be the only factor that caused tussock moth control to be deferred until an outbreak reached its decline phase.

Table 5--Relative economic efficiencies (discounted at 4 percent) of scenarios analyzed for the Clearwater National Forest

Scenario	(1) Present net value	(2) Present value of DFTM loss	(3) Net benefits of control scenarios
		Millions of dollars	
No outbreaks	1,349	NA 1/	NA
No control	1,329	20	NA
Peak phase control	1,345	4	16
Decline phase control	1,337	12	8

1/ NA = not applicable.

Table 6--Relative economic efficiencies (discounted at 4 percent) of scenarios analyzed for the Malheur National Forest

Scenario	(1) Present net value	(2) Present value of DFTM loss	(3) Net benefits of control scenarios
		Millions of dollars	
No outbreaks	1,434	NA 1/	NA
No control	1,169	265	NA
Peak phase control	1,418	16	249
Decline phase control	1,251	183	82

1/ NA = not applicable.

Conclusions

The study simulated the effects of a series of tussock moth outbreaks on the Clearwater and Malheur National Forests. The results of this simulation process indicate the following:

° Although the two Forests differ in many respects, the relative ranking of the present net values of the four scenarios was identical. Because the identical ranking resulted from testing many possible combinations of silvicultural treatments and tussock moth control under different management constraints, the tussock moth appears to threaten forest productivity under a variety of circumstances.

° For the two Forests analyzed, control of Douglas-fir tussock moth is an economically efficient forest management practice over the long run. This result does not mean that it is worthwhile to control all outbreaks as they occur. Each outbreak must still be evaluated on an individual basis to determine if control is warranted.

° Tussock moth damage can be reduced more efficiently with a combination of control and intensive silvicultural treatments than with either tactic alone.

° A tussock moth outbreak can be dealt with more efficiently during its peak phase than during its decline phase. Control during the decline phase, however, is more efficient than no control at all.

Implications

° On a Forest, the four scenarios can be directly compared and used to determine the most efficient course of action within the context of expressed management objectives (defined before the analysis). However, the results cannot be used to compare one Forest to another: Land management objectives and constraints, which affect the present net value calculations, differ. Thus, for any given Forest, the scenario with the highest present net value is the most efficient; but if Forest A has a higher present net value than Forest B, it does not follow that Forest A is more efficient than Forest B.

° Although this analysis presents a case study of two National Forests, the methodology can be applied to other lands as well, provided that management objectives are known and the necessary data are available. The basic procedure of linking three model components--an insect outbreak model, a growth and yield model, and an economic optimization model--applies to all lands. The DFTM Model and Prognosis can be used on any lands for which they are calibrated. FORPLAN is the standard planning tool used on all National Forests and is, therefore, the economic component for this analysis. On other Federal, State, or private lands where FORPLAN may not be applicable, another economic model--either a linear program or some other type of optimization procedure--can be substituted for FORPLAN. The four scenarios are appropriate for all lands.

° For the two Forests analyzed, relatively nonintensive management on a Forest-wide basis is the most efficient course of action if tussock moth outbreaks do not occur. However, relatively intensive management on a Forest-wide basis--both with and without control--becomes more efficient if tussock moth outbreaks occur. Thus, it seems prudent for the land manager to consider the likelihood of future tussock moth outbreaks when evaluating forest land management options.

° The cost of controlling tussock moth infestations was estimated to be $10 per acre (in first quarter 1978 dollars) for both the peak phase and decline phase scenarios. It was assumed that no additional costs would be incurred to undertake control in the peak phase, or second year of an outbreak, and that only administrative delays would cause control efforts to be deferred until the decline phase, or third year. But if detection expenditures are low, outbreaks may not be discovered in time to initiate control efforts during the peak phase. Consequently, additional detection expenditures may be needed to make peak phase control a viable option, and these costs must be included in the peak phase control scenario.

° Where mortality occurs over relatively large acreages, enough dead trees may be salvaged to produce a net return on the salvage operation. In other words, the revenues gained from selling the trees exceed the costs of harvesting. Salvage tends to lessen the adverse economic impact of the tussock moth, thereby increasing the present net value of the no-control scenario. On the Malheur, all mortality occurring within 10 years of a scheduled harvest was salvaged. On the Clearwater, salvage was not modeled but would have occurred if the dead trees could have been included in normal timber sales.

° The scope of this analysis covers entire Forests over 150 years; the analysis is not intended to evaluate the efficiency of controlling a specific infestation in a specific Forest stand. Although this analysis shows that the peak phase control scenario is the most efficient over the long run, this result does not mean that each and every infestation in each and every forest stand should be controlled. Rather, this analysis serves as a planning tool. It provides the land manager with information about the likely economic impact of the Douglas-fir tussock moth on forest management objectives and the most efficient actions to deal with this pest on a long-term basis. As such, this analysis is most useful for planning and evaluating land management options. As tussock moth outbreaks are discovered, they should be evaluated on a site-specific basis--from biological, environmental, and economic standpoints--to determine if control is warranted.

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Appendix A

Combined Prognosis/DFTM Model

The Combined Stand Prognosis/Douglas-fir Tussock Moth Outbreak Model (Monserud and Crookston 1982) is a computer model that simulates the development of forest stands affected by the Douglas-fir tussock moth. It combines two independent models: the Stand Prognosis Model and the Douglas-fir Tussock Moth Outbreak Model.

The first part of the combined model is the Stand Prognosis Model (Prognosis) (Wykoff and others 1982). Prognosis is an individual tree-based model that projects the growth and yield of mixed species conifer stands. The model is made up of individual components for tree diameter growth, height growth, crown ratio, and mortality. Projections are produced by adding diameter growth, height growth, and crown ratio over periodic increments (normally 10-year periods) and by reducing the number of trees (through periodic mortality) from the initial stand inventory. Prognosis produced the yield tables that the Clearwater and Malheur National Forests are using in their Forest planning process.

The Douglas-Fir Tussock Moth Outbreak Model (DFTM Model) (Colbert and others 1979), the second part of the combined model, simulates the effects of a 4-year (phase) tussock moth outbreak on a group of midcrown sample branches. Tussock moth defoliation of a sample branch is translated into percentage of tree defoliation, which, in turn, can (1) retard diameter and height growth; (2) reduce total height and volume because of top-kill; and (3) increase tree mortality.

The Combined Prognosis/DFTM Model incorporates a probability-of-outbreak component. This component (1) stochastically generates tussock moth outbreaks with minimum specified time intervals between outbreaks; (2) determines the probability of a stand with particular characteristics being part of an outbreak; and (3) subjects stands to outbreaks based on (1) and (2) above. Thus, in combination, Prognosis and the DFTM Model simulated the effects on growth, yields, and volumes of repeated, regional Douglas-fir tussock moth outbreaks over 150 years.

FORPLAN

FORPLAN (an acronym for FORest PLANning) is a linear programing model used to develop and evaluate alternative ways of managing National Forest lands. It is used by all National Forests for long-range planning.

FORPLAN is the third in a series of linear programing models developed by the Forest Service to aid in resource management planning. Timber RAM (an acronym for Resource Allocation Model) and MUSYC (an acronym for Multiple Use Sustained Yield Calculation), its two predecessors, are single resource

models designed to evaluate timber allocation alternatives. FORPLAN is designed to evaluate alternatives involving multiresource outputs.

Linear programing is a mathematical optimization technique. It is most useful in analyzing large quantities of interdependent information to determine which of many possible combinations results in a desired outcome. The desired outcome is defined by the users and is often stated in terms of "maximizing" or "minimizing" some quantifiable value such as benefits or costs.

In this study, FORPLAN maximizes present net value for each scenario by selecting a combination of silvicultural treatments and harvest options that can produce the highest present net value and still meet managerial and legal constraints.

Appendix B

Timber Inventory Designs

FORPLAN uses yield tables as the basic information for all resources and functions that the land manager wishes to evaluate. The yield tables in this study were developed by Prognosis, which uses a tree list as the starting point for its growth and yield projections. Tree lists are developed from data generated from forest inventory plots. The timber inventories on the Clearwater and Malheur National Forests have different designs. Because the inventories are basic to the planning process and their designs affect the way data can be processed, the inventory designs of each Forest are briefly described.

Clearwater Inventory Design

The Clearwater National Forest inventory is designed with sample units of about 500 acres. Sample units are chosen with the probability of their selection proportional to the acreage (probability proportional to size). Stands are identified over the entire Forest; consequently, areas chosen as sample units contain stands or portions of stands or both. Sample plots are distributed over each sample unit using a systematic grid so that each sample plot represents 5 acres. Each stand is sampled by the plots that fall within the stand.

For each stand, an area expansion factor is calculated based on its acreage and the selection probability of the sample unit in which the stand is located. The area expansion factor is used to calculate acreage of the National Forest represented in the sample. Stand development was projected using Prognosis or the Combined Prognosis/DFTM Model under a variety of silvicultural treatment options. The individual stand projections are aggregated to form yield tables. In this process, the per-acre volume of each stand is weighted by its area expansion factor.

Malheur Inventory Design

The Malheur National Forest's inventory has a random plot design. The Forest is classified by timber type and silvicultural treatment options (for example, the mixed conifer/commercial thinning class). Four hundred samples are distributed among twelve classes. At each sample location, 10 plots are installed; and data, such as diameter, species, and tree class, are recorded. Appropriate data from the sample locations are then combined, and Prognosis or the Combined Prognosis/DFTM Model run to produce yield tables. Thus, in the process of producing the Malheur's yield tables, the combined data for each class were essentially treated as a stand.

Appendix C

Table 1--Stumpage values on the Clearwater National Forest

Diameter class	Grand fir, cedar		Alpine fir		Mountain hemlock	
	55% + slope	0-55% slope	55% + slope	0-55% slope	55% + slope	0-55% slope
Inches	*Dollars per thousand cubic feet*					
7.0 to 11.9	NA 1/	NA	- 174	7	- 184	6
12.0 to 14.9	134	258	52	200	47	197
15.0 to 17.9	172	304	84	238	76	227
18.0 to 20.9	209	346	114	272	103	256
21.0 to 23.9	245	385	144	306	129	283

1/ NA = not applicable.

Table 2--Stumpage values on the Malheur National Forest

Diameter class	Ponderosa pine		Mixed conifer		Lodgepole pine	
	35% + slope	0-35% slope	35% + slope	0-35% slope	35% + slope	0-35% slope
Inches	*Dollars per thousand cubic feet*					
7.0 to 11.9	- 107	50	- 79	77	- 64	93
12.0 to 14.9	198	354	138	294	68	224
15.0 to 17.9	384	540	295	452	163	319
18.0 to 21.9	600	756	479	635	274	430
22.0 to 25.9	848	1,004	690	845	401	557
26.0 +	954	1,110	NA 1/	NA	NA	NA

1/ NA = not applicable.

Appendix D

The Combined Prognosis/DFTM Model was calibrated to simulate the historical patterns and intensities of tussock moth outbreaks on the Clearwater and Malheur National Forests. The keywords and parameters used in this analysis to run the DFTM portion of the Combined Prognosis/DFTM Model were as follows:

Keywords

1. DFTM.--This keyword directs Prognosis to read and process DFTM Model keywords.

2. RANSCHED.--This keyword, which generates a list of regional outbreaks, has three associated fields:

Field 1 specifies the minimum waiting time between outbreaks. This was set at 9 years for the Clearwater and 10 years for the Malheur.

Field 2 sets the annual probability of a regional outbreak after the minimum waiting time since the last outbreak is exceeded. A value of 0.4 was used for the Clearwater and 0.1 was used for the Malheur to simulate historical frequencies.

Field 3 specifies the calendar year of the last regional outbreak: 1973 was used for the Clearwater and 1965 was used for the Malheur.

3. RANSTART.--This keyword invokes a random number generator to determine if a particular stand will be infested by tussock moth, given a regional outbreak. RANSTART is used in conjuction with keyword 4.

4. PROBMETH.--This keyword is used with RANSTART and selects the conditional probability that a stand becomes involved in a regional outbreak. This keyword has two fields:

Field 1 is used to specify the method by which the conditional probability of a particular stand being included in a regional outbreak is calculated. Method 2 was specified for the Clearwater National Forest and method 1 was specified for the Malheur. In method 1, the conditional probability of a stand being included in a regional outbreak depends upon elevation, slope, aspect, topographic position, stand closure, proportion of stand in host, and average crown width. Method 2 uses topographic position, ash depth in inches, total basal area, and proportion of stand in grand fir.

Field 2 is a conditional probability scaling factor. A scaling factor of 1.0 leaves the conditional probability calculated in methods 1 and 2 above unchanged. A factor of 0.5 would reduce the conditional probability by one-half. For this analysis, a scaling factor of 1.0 was used for the Clearwater and a scaling factor of 0.5 was used for the Malheur.

Method 1 is based on data taken from the Umatilla and Wallowa-Whitman National Forests during the 1971-74 outbreak. This outbreak approached 0.5 million acres and included most stands in the outbreak area. However, the tussock moth history on the Malheur does not support the assumption that an outbreak of the magnitude experienced on the Umatilla and Wallowa-Whitman National Forests will occur with any certainty. Therefore, the conditional probability determined by method 1 was scaled down by one-half for the Malheur National Forest. The end result of this adjustment was a reduction by one-fourth in the number of stands included in regional outbreaks over the 150-year planning period.

5. TOPO.--This keyword is used to specify the topographic position of a stand as (1) ridgetop, (2) sidehill, or (3) bottom. For both the Clearwater and Malheur, number 2--sidehill--was chosen to reflect average conditions.

6. RANLARVA.--This keyword randomly allocates first instar tussock moth larvae to host trees at the start of every outbreak. It has four fields:

Field 1. Host species, either Douglas-fir or grand fir, may be specified. Both were used, depending on the predominant host species in the simulation.

Field 2. Number of first instar larvae to approximate local conditions. Values of 9 and 11 larvae per sample branch were specified for Douglas-fir and grand fir, respectively, for the Malheur. Values of 7 and 9 larvae per sample branch for Douglas-fir and grand fir, respectively, were specified for the Clearwater.

Field 3. Within-outbreak standard deviation of the number of first instar larvae. Larval numbers were drawn from a normal distribution and allocated to trees based on the mean density in field 2 and the standard deviation of the normal distribution in field 3. Field 3 was set at 5 for the Clearwater and 3 for the Malheur.

Field 4. Between-outbreak standard deviation of the number of first instar larvae. Larval densities at the start of an outbreak were drawn from a normal distribution based on the number in field 2 and the standard deviation in field 4. The between-outbreak standard deviation was set at 5.0 for both Forests.

7. BIOMASS.--This keyword is used to specify the method for calculating foliage biomass and the percent of new foliage per sample branch. Method 4 was used for both Forests.

8. NUMCLASS.--This keyword specifies the number of tree classes to be used for each of the tree species. It has three fields:

Field 1 is the number of tree classes for Douglas-fir. (Set at 15 for both Forests.)

Field 2 is the number of tree classes for grand fir. (Set at 15 for both Forests.)

Field 3 is involved with the mathematical procedures of creating the tree classes. A value of 0.5 was used for both Forests.

9. REDIST.--This keyword specifies the annual redistribution rate of tussock moth between tree classes. The default rate of 0.25 was used for both Forests.

10. NPV 2 and NPV 3.--These keywords were used for both Forests to simulate the effects of control using nuclear polyhedrosis virus (NPV) in the peak and decline phases of the outbreak, respectively. Use of the chemical control keyword (CHEMICAL) with a 90-percent tussock moth mortality will approximate the results of using the NPV keyword.

11. END.--This keyword is used to end tussock moth keyword input.

Appendix E

Table 1--Economic values discounted at 7.125 percent for the Clearwater National Forest

Scenario	Present value of benefits	Present value of costs	Present net value	Present value of DFTM loss	Net benefits of control scenarios
	Millions of dollars				
No outbreaks	670	170	500	NA 1/	NA
No control	668	177	491	9	NA
Peak phase control	669	173	496	4	5
Decline phase control	668	175	493	7	2

1/ NA = not applicable.

Table 2--Economic values discounted at 7.125 percent for the Malheur National Forest

Scenario	Present value of benefits	Present value of costs	Present net value	Present value of DFTM loss	Net benefits of control scenarios
	Millions of dollars				
No outbreaks	775	58	717	NA 1/	NA
No control	639	51	588	129	NA
Peak phase control	777	64	713	4	125
Decline phase control	686	57	629	88	41

1/ NA = not applicable.

Appendix F

Table 1--Acres and volumes thinned

Scenario	Precommercial thinnings	Commercial thinnings	Commercial thinnings
	Thousands of acres		*Million cubic feet*
Clearwater National Forest			
No outbreaks	29	232	377
No control	17	230	369
Peak phase control	33	236	379
Decline phase control	41	243	391
Malheur National Forest			
No outbreaks	2,065	1,373	1,292
No control	1,910	1,431	1,333
Peak phase control	2,121	1,531	1,506
Decline phase control	1,803	1,281	1,224

Appendix G

Contributing Authors

Bousfield, Wayne E.	Entomologist, Cooperative Forestry and Pest Management, Missoula, Mont.
Brickell, James E.	Biometrician, Timber Management, Missoula, Mont.
Cleeves, John C.	Forester, Clearwater National Forest, Orofino, Idaho
Dezellem, Richard L.	Forester, Malheur National Forest, John Day, Oreg.
Gregg, Tommy F.	Forestry Technician, Forest Pest Management, Portland, Oreg.
Hofacker, Thomas H.	Entomologist, Forest Pest Management, Washington, D.C.
Johnson, Ralph R.	Forest Management Systems Specialist, Cooperative Forestry and Pest Management, Missoula, Mont.
Lewis, Joseph W.	Economist, Forest Pest Management, Washington, D.C.
Lightner, George M.	Forester, Clearwater National Forest, Orofino, Idaho
Quinn, Thomas P.	Economist, Boise National Forest, Boise, Idaho (formerly Malheur National Forest)
Wiitala, Marc R.	Economist, Cooperative Forestry, Portland, Oreg.

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